Satellite and Terrestrial Narrow-Band Propagation Measurements At 2.05 GHz

A. Vaisnys Jet Propulsion Laboratory, California Institute of Technology
W. Vogel EERL/University of Texas at Austin

1. Introduction

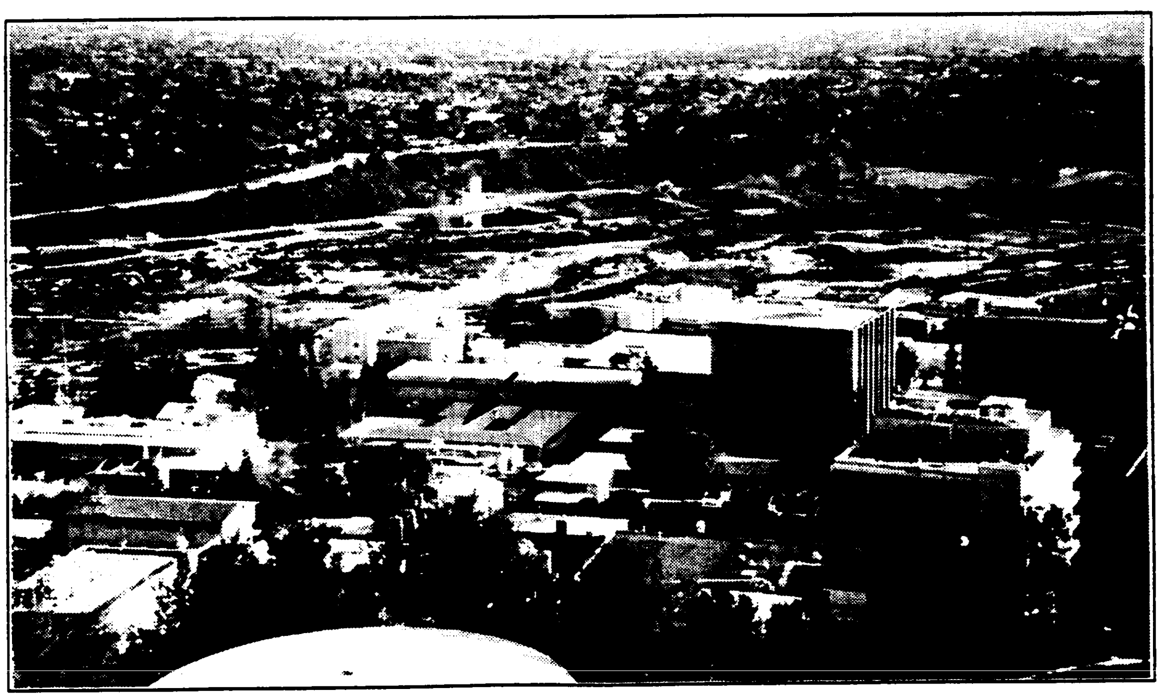
A series of satellite and terrestrial propagation measurements were conducted on 15 and 16 December, 1994 in the vicinity of the Jet Propulsion Laboratory (JPL), Pasadena, California, in support of the VOA/JPL DBS-Radio Program. The reason for including terrestrial measurements was the possible use of terrestrial boosters to improve reception in some satellite digital audio broadcasting system service areas.

The signal sources used were the NASA TDRS satellite located at 171 degrees West and a terrestrial transmitter located on a high point on JPL property. Both signals were unmodulated carriers near 2.05 GHz, spaced a few kHz apart so that both could be received simultaneously by a single receiver. An unmodulated signal was used in order to maximize the dynamic range of the signal strength measurement. A range of greater than 35 dB was achieved with the satellite signal, and over 50 dB was achieved with the terrestrial signal measurements.

Three test courses were used to conduct the measurements:

- A 33 km round trip drive from JPL through Pasadena was used to remeasure the propagation of the satellite signal over the path previously used in DBS-Radio experiments in mid 1994. A shortened portion of this test course, approximately 20 km, was used to measure the satellite and terrestrial signals simultaneously.
- A 9 km round trip drive through JPL property, going behind buildings and other obstacles, was used to measure the satellite and terrestrial signals simultaneously.
- A path through one of the buildings at JPL, hand carrying the receiver, was also used to measure the satellite and terrestrial signals simultaneously.

Below is a photograph of the view from the terrestrial transmit site down to JPL and toward Pasadena. The horizon is Colorado Boulevard, which marks the far point of the Pasadena runs. Building 161, which was the site of the indoor measurement, is indicated.



2. Test Configuration

The receiving system configuration for the automobile mounted equipment is shown in Figure 1. The receiving antenna was a bifilar helix with a gain of 8 dBi at 25 degrees' elevation. This was followed by a low noise amplifier and a receiver which converted the signal to the audio frequency range between 2.5 kHz and 7.5 kHz. This signal was recorded on a digital audio tape (DAT) recorder at a sampling rate of 48 kHz. Post processing was then used to filter and detect the signal amplitude and phase. The resultant data was provided at a sample rate of 1000 samples per second.

The configuration used indoors was the same except that the antenna was omnidirectional, with approximately 0 dBi gain.

All of the outdoor tests also included recording with two vehicle mounted video cameras, one facing forward and the other a fisheye lens facing up. A global positioning system (GPS) receiver was used to record vehicle position, speed and heading.

The direction to the satellite was 248 compass degrees (South of West) and the elevation angle was 22 degrees. The direction to the terrestrial transmitter was generally to the North or Northwest.

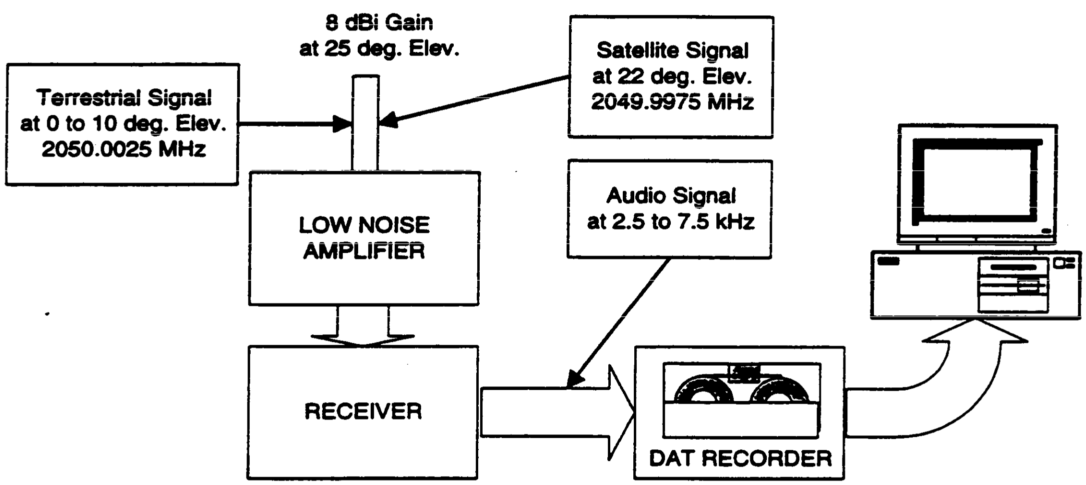


Figure 1. Receiving System Configuration

3. Test Results

The complete set of test data is documented in University of Texas Report EERL-95-B1, 10 February, 1995. This paper presents a selection of the test results and some conclusions on the differences in propagation of satellite and terrestrial signals.

3.1. Pasadena Run 1 - Satellite Signal.

The Pasadena long path was used in a previous test, in mid 1994, to test the performance of the VOA/JPL DBS Receiver with TDRS. Signal drop-outs were experienced due to blockage by buildings and trees. The signal strength measurement showed sharp signal drops during blockage, but being a wide band measurement, it could not achieve a dynamic range of more than about 10 dB. The main purpose of the December 1994 test run 1 was to retest this path with a much wider dynamic range signal measurement.

Figure 2 shows a map of the test route, with a short description of the terrain given in Table 1. Figure 3 shows a GPS derived plot of the vehicle position during the test run.

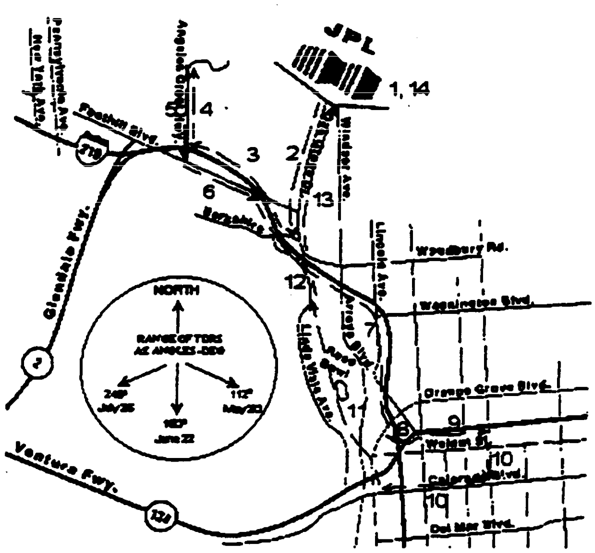


Figure 2. Test Route

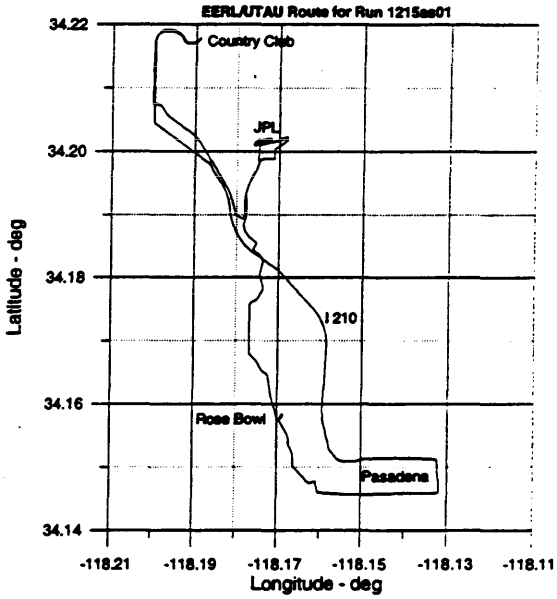


Figure 3. GPS Derived Vehicle Position

Table 1. Test Route Description

Buildings and trees on JPL property	1
Medium width, 4 lane , street with trees at varying distance from roadway	2
Above street level freeway with occasional overpasses	3
Wide, 4 lane, street with trees at varying distance from roadway (North)	4
Wide, 4 lane, street with trees at varying distance from roadway (South)	5
Commercial with low buildings	6
Above street level freeway with occasional overpasses	7
Two long tunnels	8
Below street level freeway with occasional overpasses	9
Commercial, mostly 3 story, but some tall buildings	10
Mixed open and some trees close to road	11
Residential heavily shaded by trees	12
Medium width, 4 lane , street with trees at varying distance from roadway	13
Buildings and trees on JPL property	14

Figure 4 is a plot of the received signal power, at 100 samples per second, relative to a line-of-sight value referenced to 0 dB. The measurement indicates that there is very little multipath under line-of-sight conditions. Most impairments are due to signal blockage by buildings and trees. Figure 5 shows the histogram and cumulative probability of the received signal power samples, which indicate that signal attenuation under the test conditions exceeded 15 dB about 10 percent of the time and 30 dB about 2 percent of the time.

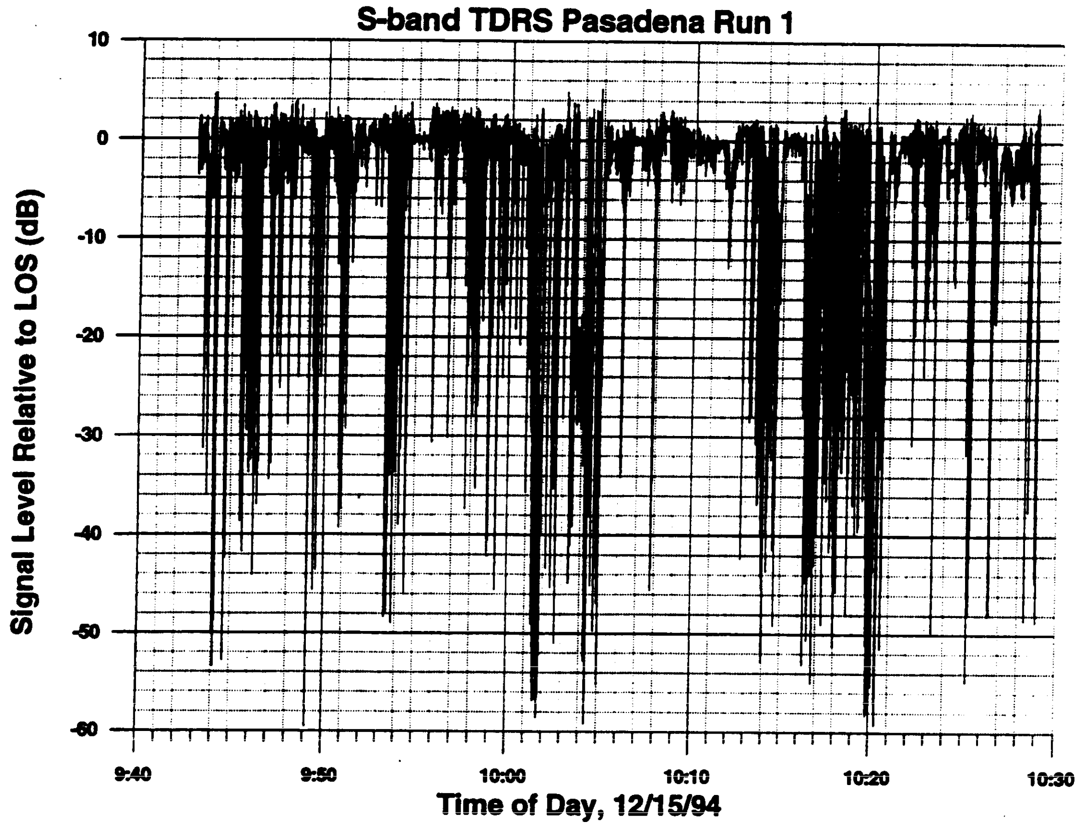


Figure 4. Received Satellite Signal Power for Run 1 (100 samples/sec.)

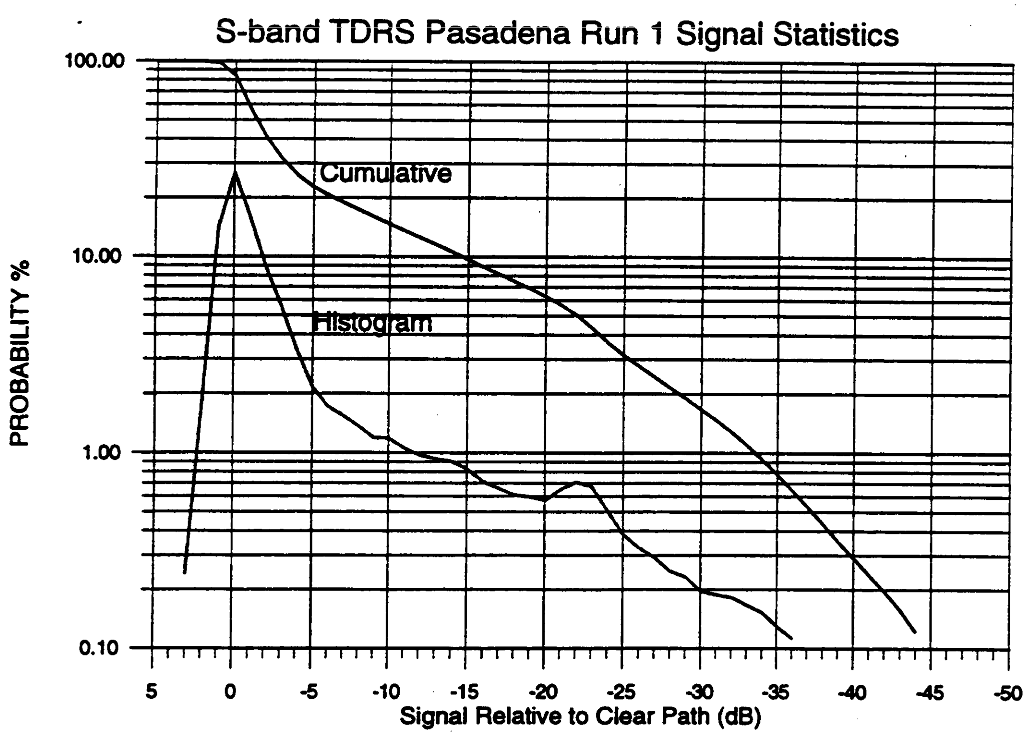


Figure 5. Signal Statistics for Run 1

3.2. Pasadena Runs 6 and 7 - Satellite and Terrestrial Signals.

These runs were conducted over the same test course as run 1, with the exception of sections 3 through 6 to the West of JPL. These sections could not be covered by the terrestrial transmitter.

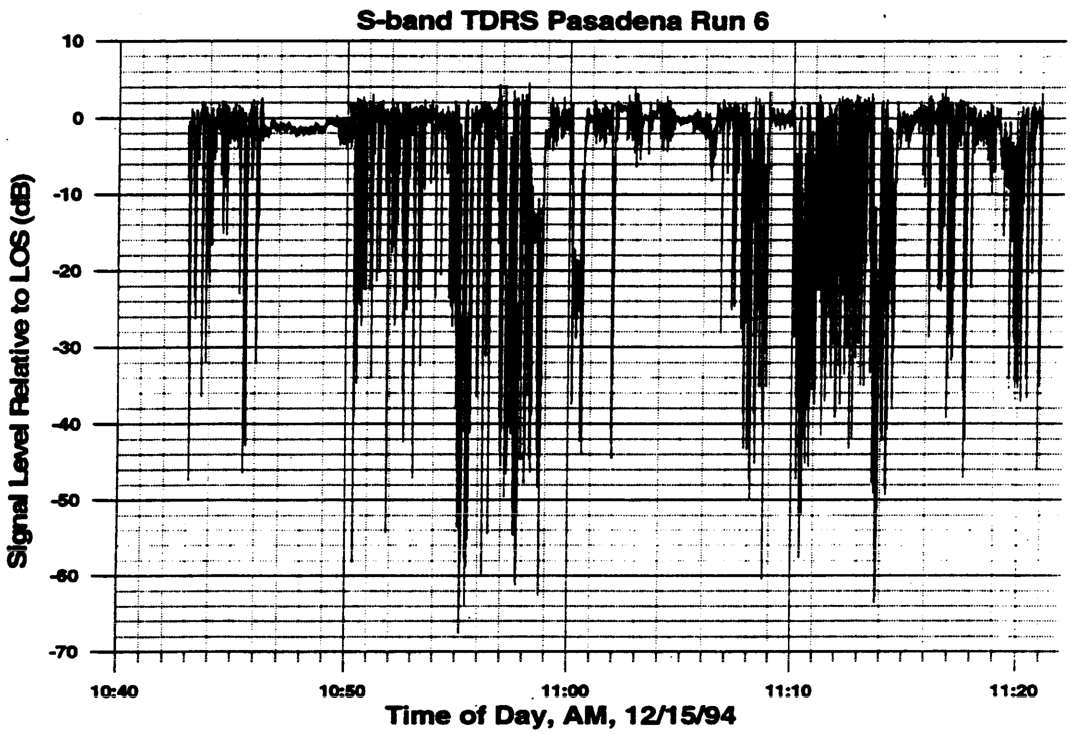


Figure 6. Received Satellite Signal Power for Run 6

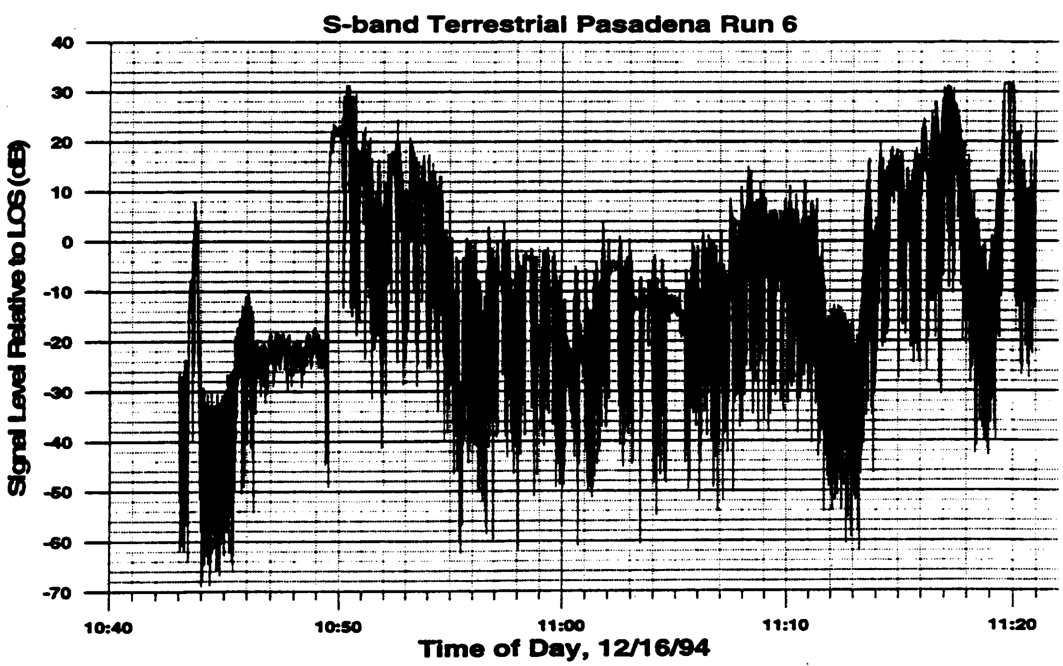


Figure 7. Received Terrestrial Signal Power for Run 6

Because of transmission at a lower elevation angle, the terrestrial signal suffers much more multipath than the satellite signal. In addition there is a greater chance of terrain blockage. Run 6 started on the hill near the terrestrial transmit site. In the initial part, from 10:43 to 10:49, the signal was blocked by the ridge upon which the transmitter was located. There are also indications of signal blockage by terrain at 11:12 and at 11:19.

Run 6 included several 360 degree loops in a parking lot. Figure 8 shows a plot of the satellite and terrestrial signal during the parking lot calibration circles. This plot also indicates that there is much more multipath for the terrestrial signal path.

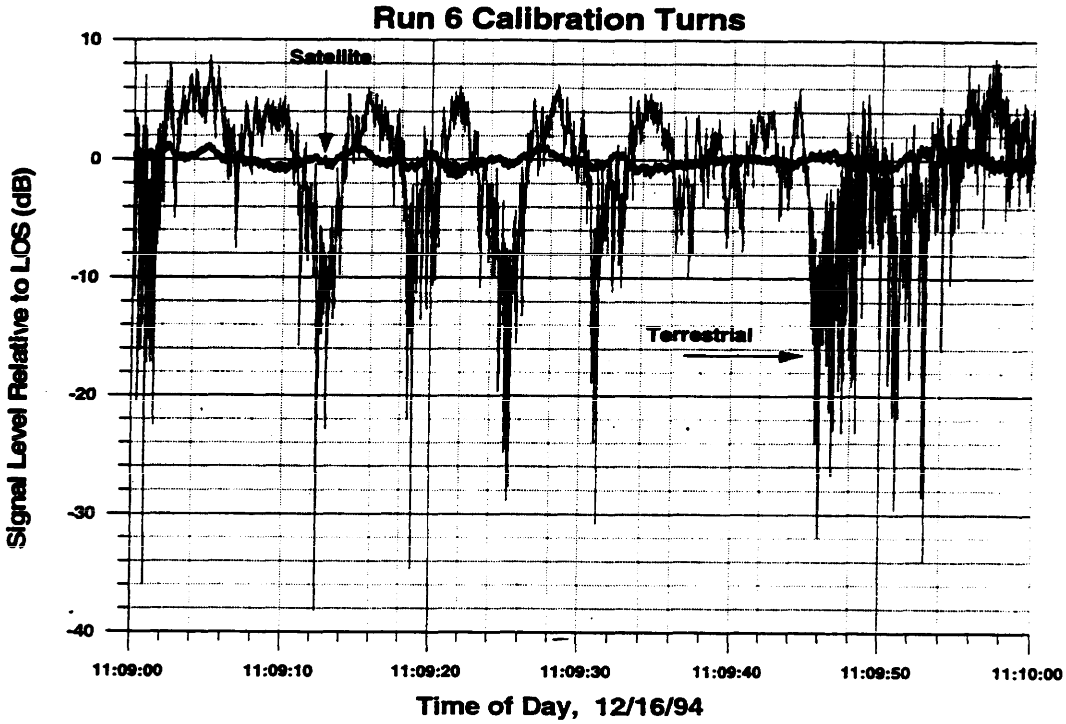


Figure 8. Satellite and Terrestrial Signal Measurement During Calibration Turns on Run 6.

Run 7 was conducted over the same test course as run 6, except that it was started past the initial area of terrestrial signal blockage. Run 7 also included a segment with the terrestrial signal turned off. which provided a calibration of the noise floor of the receiver for the terrestrial signal measurement.

Figures 9 and 10 show the received satellite and terrestrial sampled signals for run 7.

Figure 11 shows the received terrestrial signal averaged with a one second running average. This shows that much of the signal fluctuation structure seen in Figure 10 is of a short term nature, a good indication that signal fluctuations are caused by multipath. Multipath effects can be overcome to some extent by antenna diversity.

The average attenuation of the terrestrial signal over the test course was not excessive. Since it is possible to have larger terrestrial signal transmitter power, the use of wide area terrestrial boosters for augmenting satellite signal reception at S-band appears promising.

Figure 12 show the signal statistics for the satellite and terrestrial signal measurements of run 7.

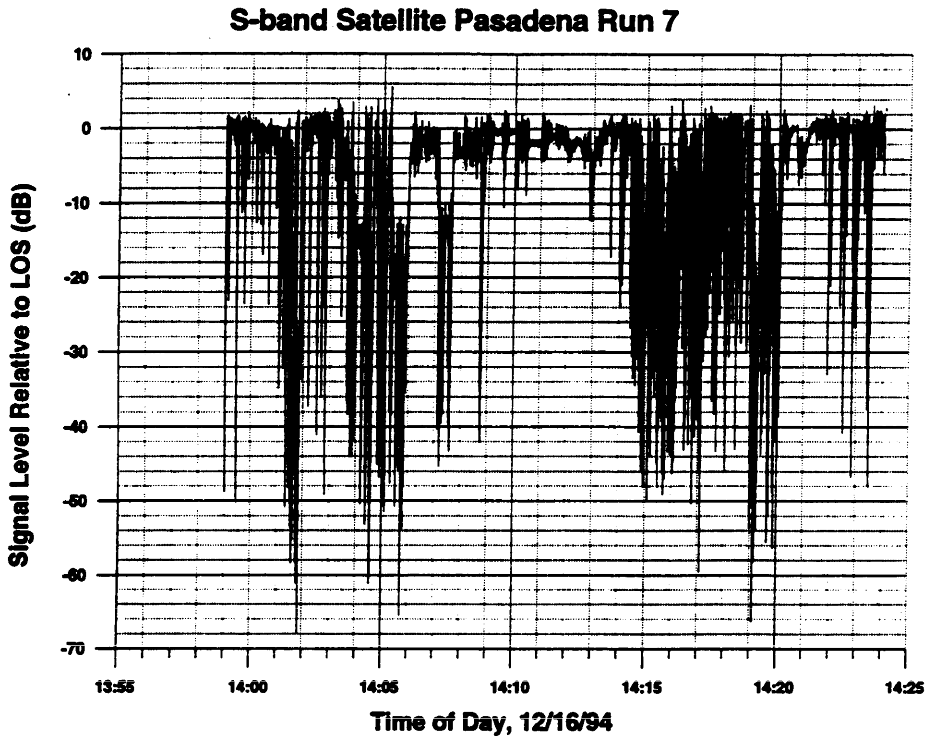


Figure 9. Satellite Signal Measurement

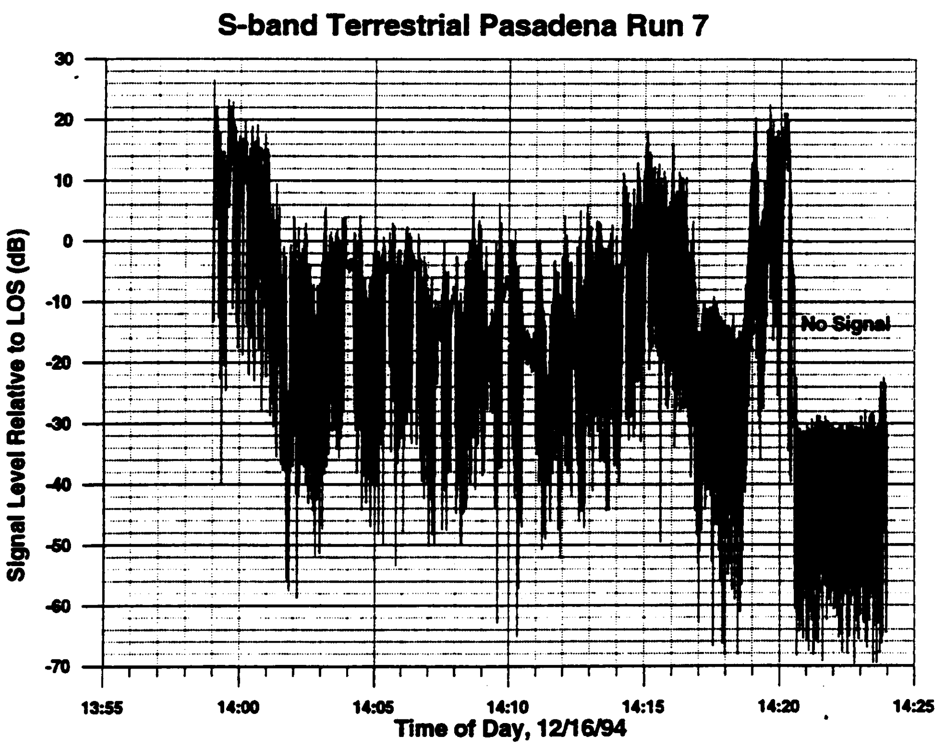


Figure 10. Received Terrestrial Signal Power

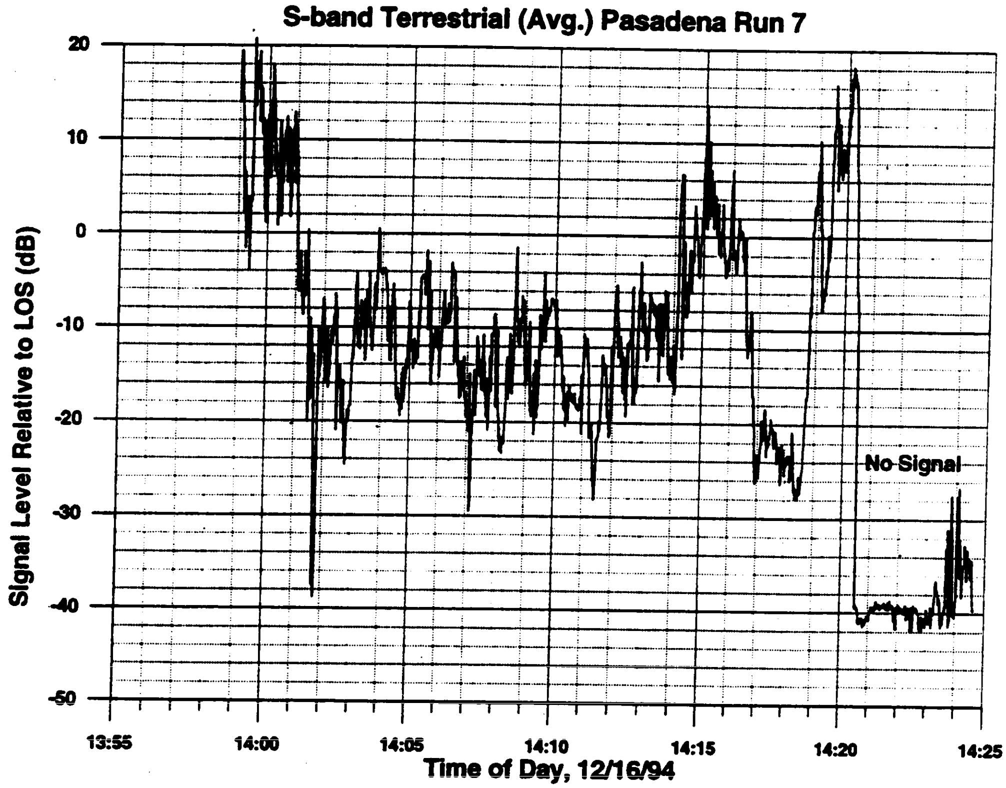


Figure 11. Received Terrestrial Signal Power for Run 7 - One Second Averages

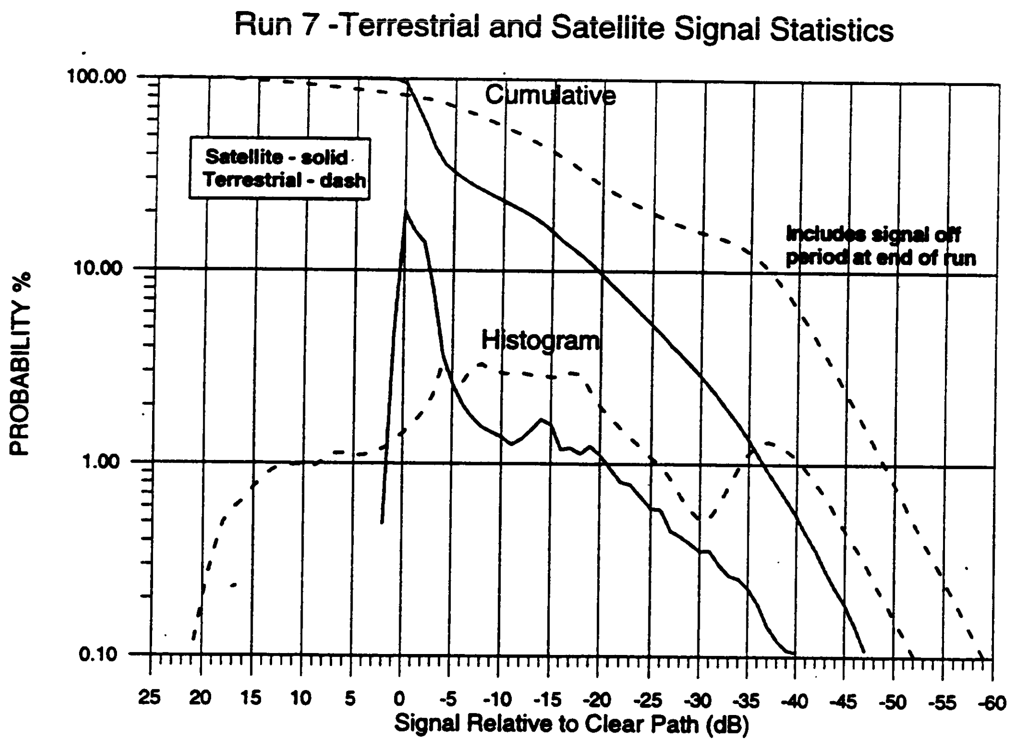


Figure 12. Histograms and Cumulative Probabilities of Received Signal Power for Run 7

3.3. <u>JPL Run 5 - Satellite and Terrestrial Signals on JPL Test Run.</u>

Run 5 was also a simultaneous measurement of the satellite and terrestrial signal, except that it was conducted over a shorter course within JPL. Figure 13 shows a map of JPL, while Figure 14 shows the GPS derived vehicle position during the test loop. Some drift in the latitude determination is apparent from this plot.

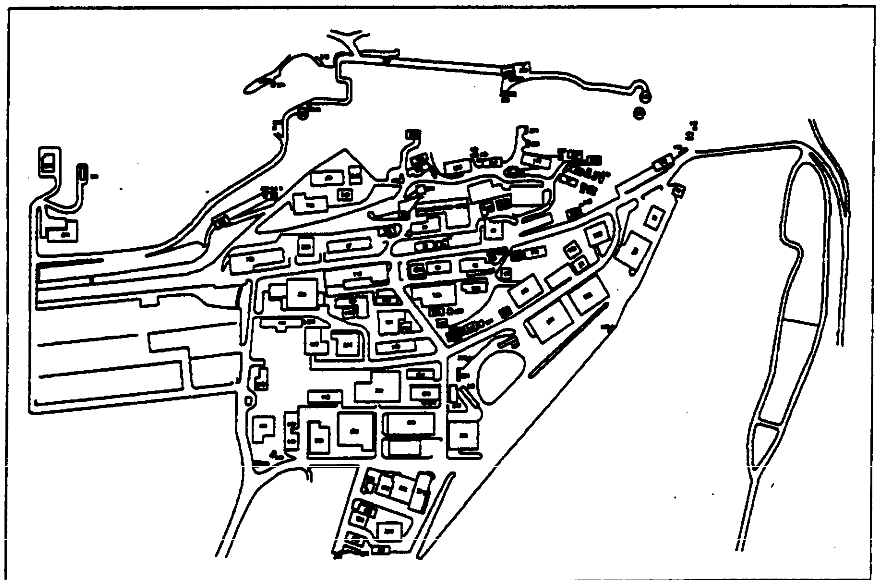


Figure 13. Map of the Jet Propulsion Laboratory

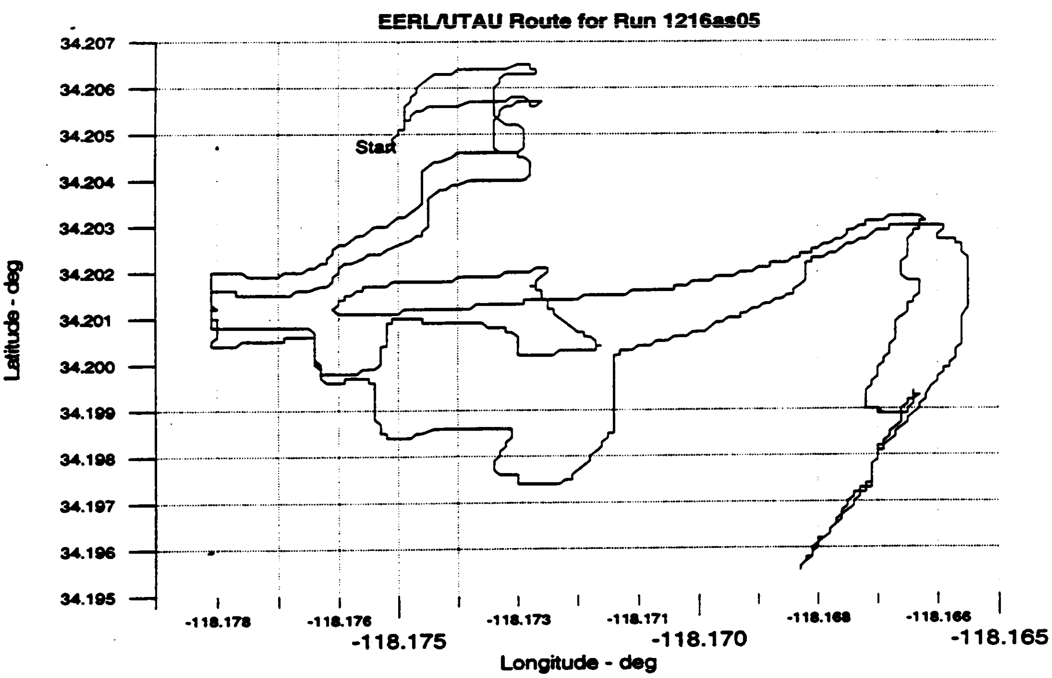


Figure 14. GPS Derived Position During Run 5

Figures 15 through 17 show the signal measurements and signal statistics for Run 5.

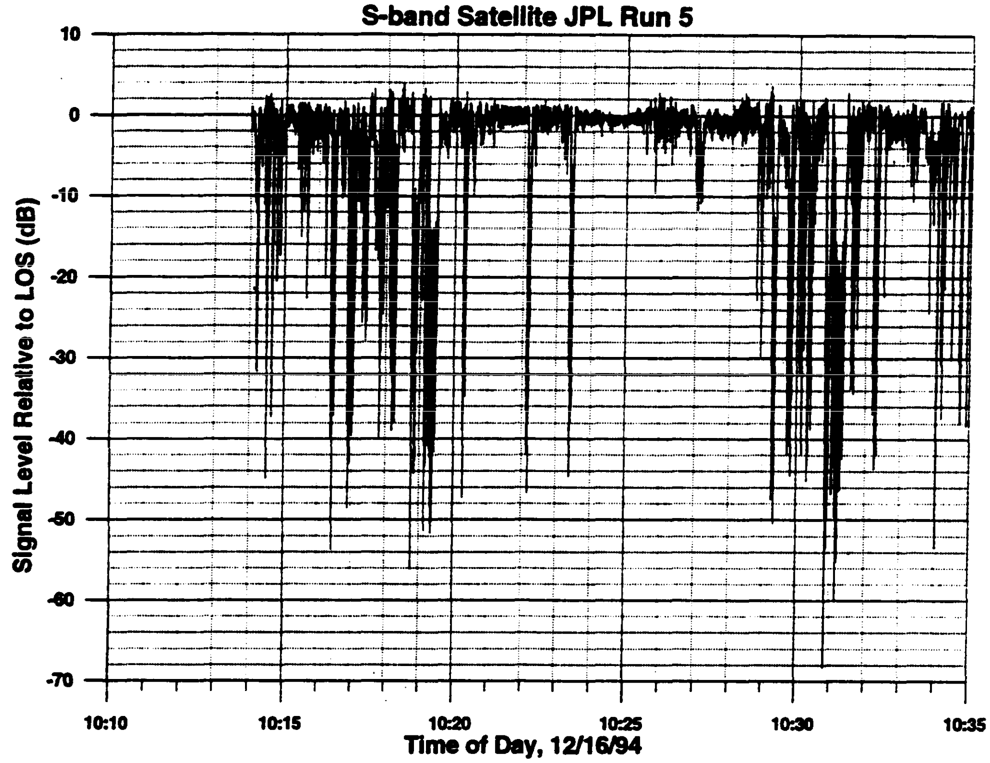


Figure 15. Received Satellite Signal Power

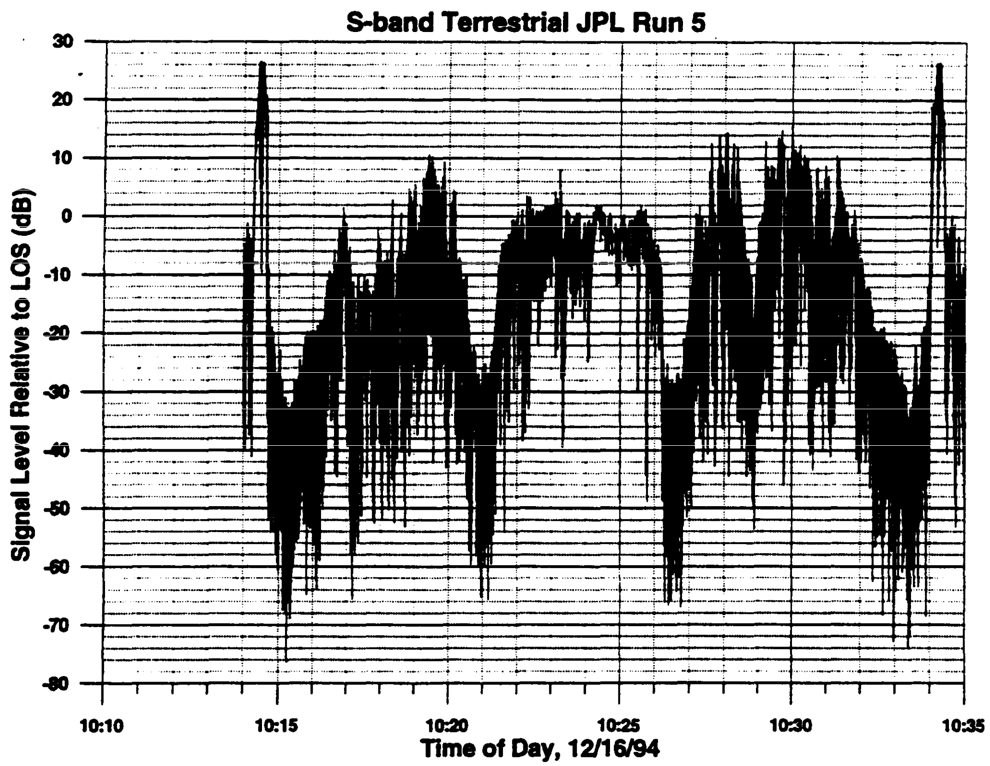


Figure 16. Received Terrestrial Signal Power

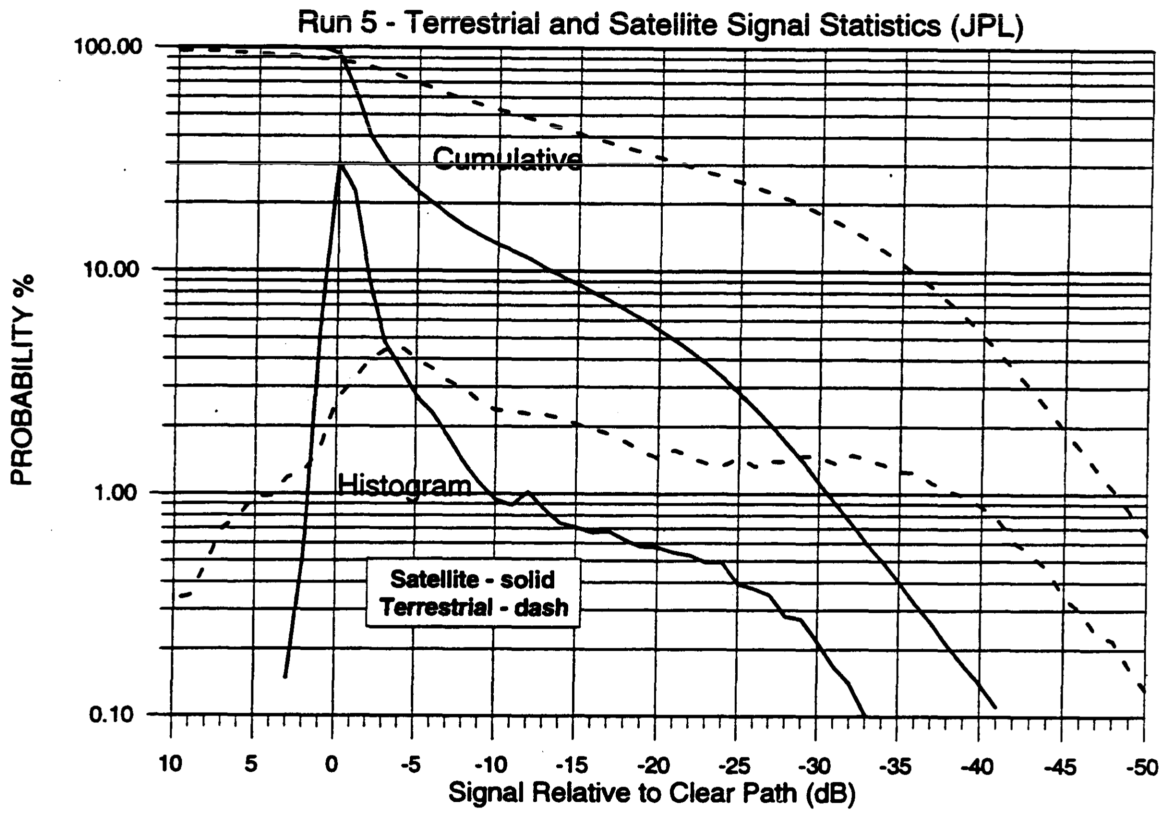
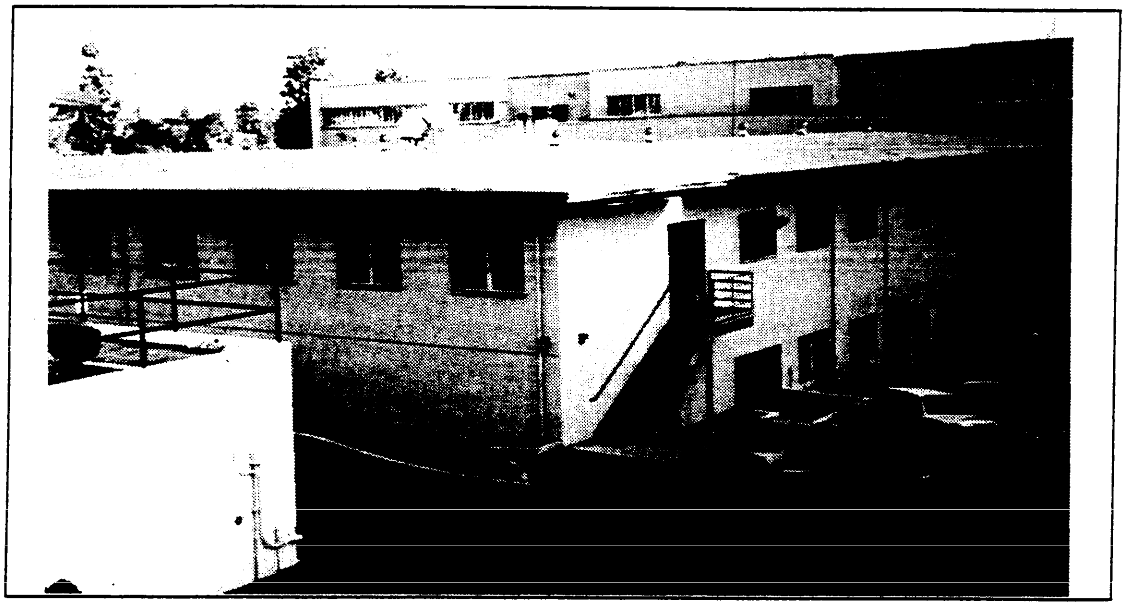


Figure 17. Histograms and Cumulative Probability of the Received Signal Power Samples for Run 5

3.4. JPL Indoor (Building. 161) - Satellite and Terrestrial Signals.

Run 8 of the measurements was conducted indoors, walking through JPL building 161. Shown below is a close-up photo of Building 161, looking from the general direction of the terrestrial transmit site.



The receiver was carried into the second floor East entrance to the building, carried through the North corridor, out through the West door (at 14:35:30), back in and down the West corridor, then back all the way to the East entrance and outside (at 14:39:40).

Figure 18 shows the signal statistics. Figures 19 through 20 show the signal power measurements. including one second averages.

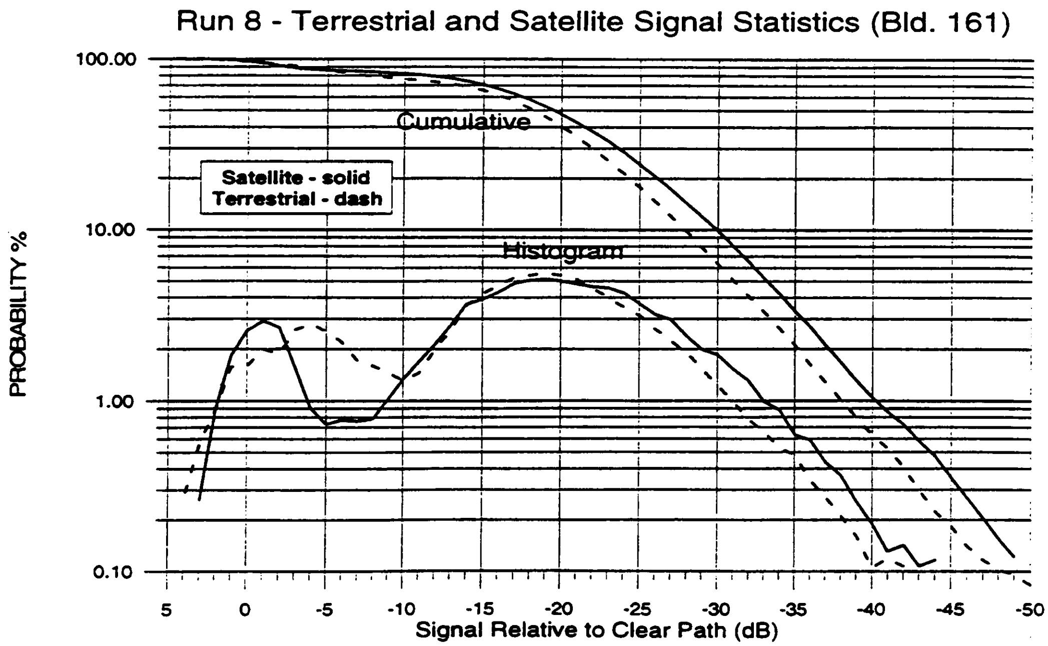


Figure 18. Signal Statistics for Run 8

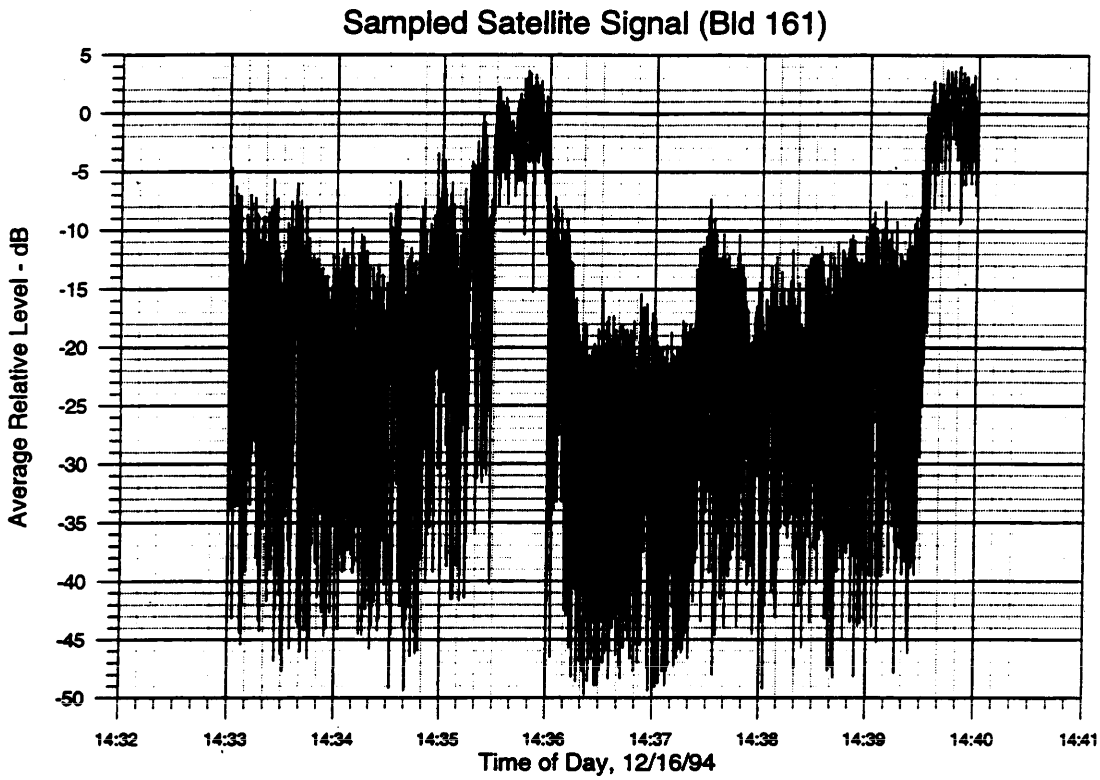


Figure 19a. Received Satellite Signal

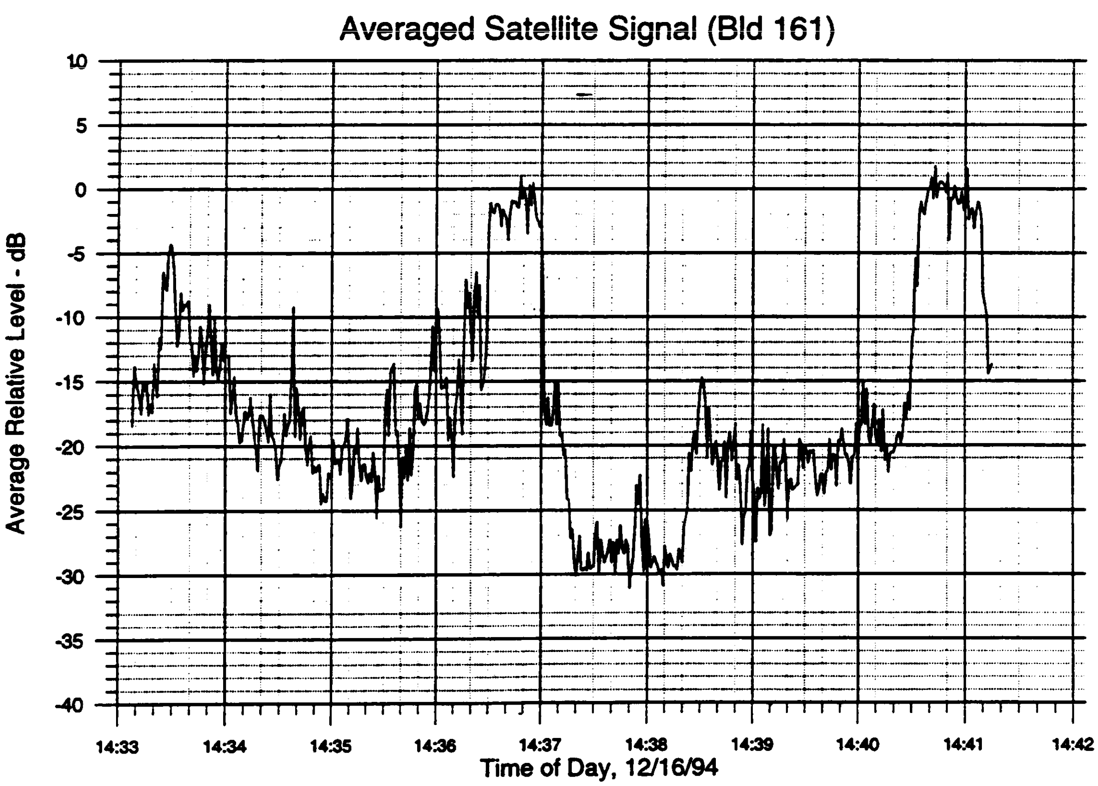


Figure 19b. Received Satellite Signal- One Second Averages

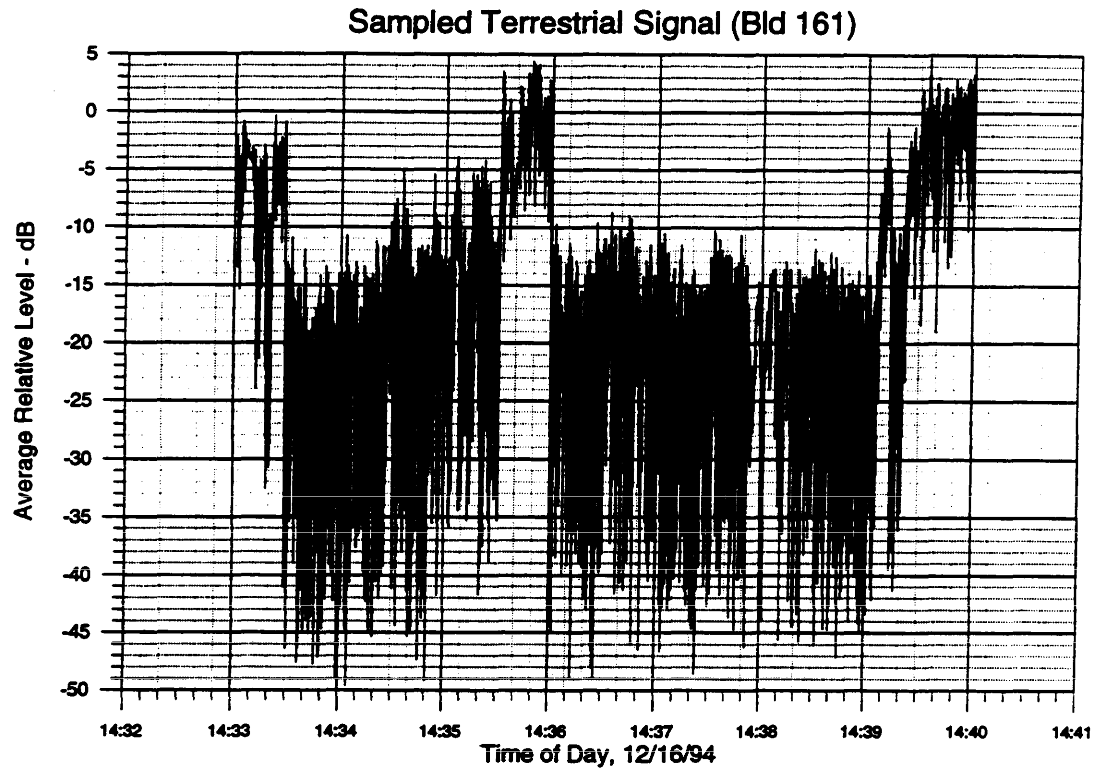


Figure 20a. Received Terrestrial Signal

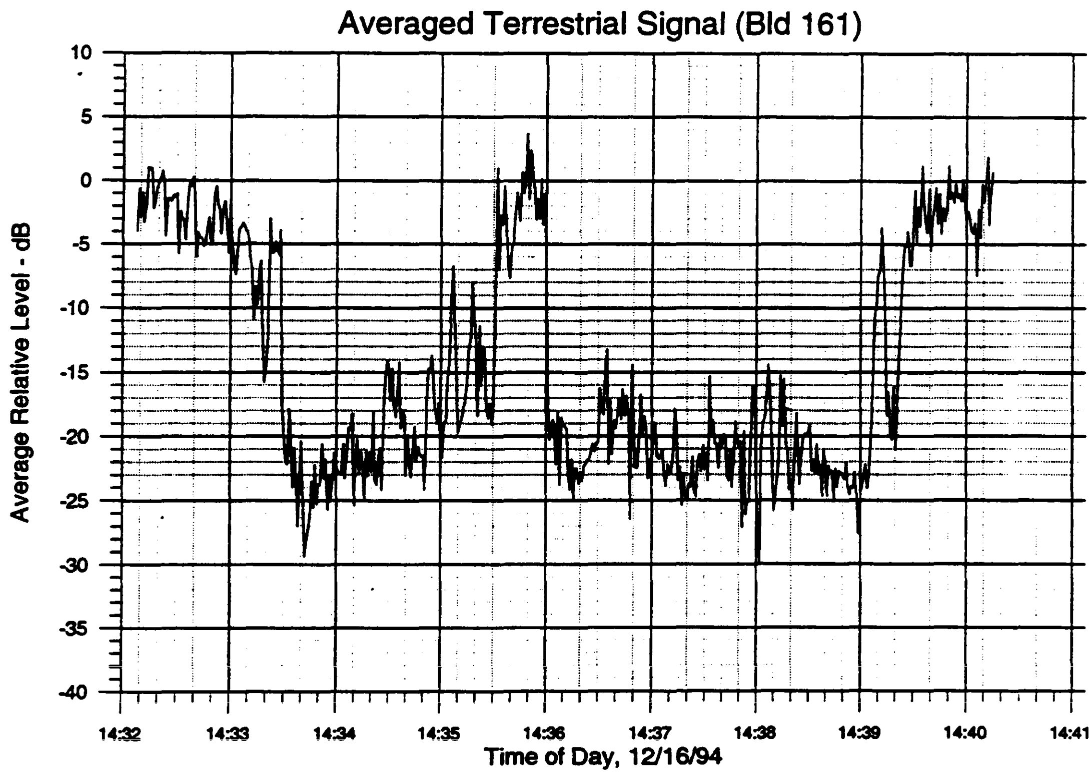


Figure 20b. Received Terrestrial Signal - One Second Averages

4.0 Summary and Conclusions.

A propagation data base at 2 GHz has been obtained through an extensive set of measurements using both a satellite and terrestrial, narrow band, signal source. The measurements were made in a variety of environments, including indoors. A video record of the outdoor measurements is available to identify the cause of the propagation impairments.

Propagation of a satellite signal, even at an elevation of 22 degrees, is characterized by minimal multipath, but very large (> 30 dB) signal drop outs due to blockage by buildings and trees. These effects cannot be compensated for by reasonable amounts of link margin. Signal or time diversity is the only viable option for improving performance.

Terrestrial transmission provides a signal which fluctuates rapidly with receiver position. Under these conditions, receiving antenna diversity, with a reasonably small antenna separation, may be effective in improving reception.

Indoors, the effect on both a satellite and terrestrial signal is similar. There is a complex standing wave structure with signal peaks and troughs on the order of fractions of wavelengths apart. This wave structure has been shown to be wide band (on the order of several MHz), as well as stable in time [1]. Because of this, it is theoretically possible to find strong signal points by moving the receive antenna around. In practice, however, this may be difficult. Receive antenna diversity may be the only practical strategy if the antenna cannot be moved outdoors or to a window facing the satellite.

5.0 References

[1] W.J. Vogel and G. W. Torrence, "Propagation Measurements for Satellite Radio Reception Inside Buildings, " *IEEE Transactions on Antennas and Propagation*, Vol. 41, No. 7, pp. 954-961, July 1993.